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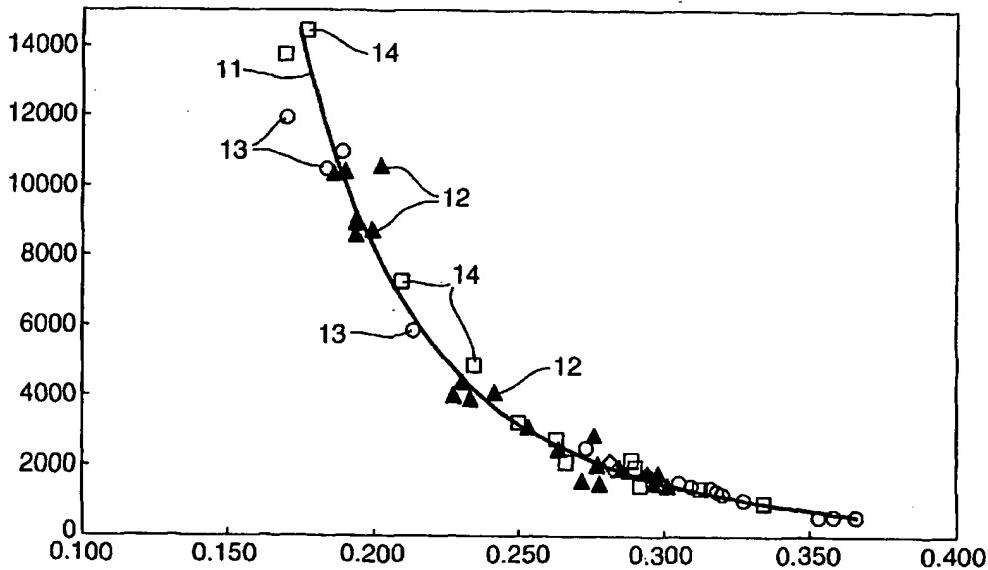
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- (71) Applicant (for all designated States except CA, US): **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V. [NL/NL]**; Carel van Bylandlaan 30, NL-2596 HR The Hague (NL).
- (71) Applicant (for CA only): **SHELL CANADA LIMITED [CA/CA]**; 400 - 4th Avenue S.W., Calgary, Alberta T2P 2H5 (CA).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): HASHEM, Mohamed, Naguib [US/US]; One Shell Square, 701 Poydras Street, New Orleans, LA 70139 (US). UGUETO, Gustavo, Antonio [VE/US]; One Shell Square, 701 Poydras Street, New Orleans, LA 70139 (US).
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(54) Title: DETERMINING THE PVT PROPERTIES OF A HYDROCARBON RESERVOIR FLUID



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(57) Abstract: A method of determining an in situ PVT property of a hydrocarbon reservoir fluid that is present in a hydrocarbon-bearing formation layer traversed by a borehole, which method comprises the steps of: a) calculating along the hydrocarbon-bearing formation layer the pressure gradient; and b) determining the in situ PVT property from the pressure gradient using an empirical relation that had been obtained by fitting a curve (11) through previously obtained data points (12, 13, 14) comprising the measured PVT property as a function of the pressure gradient.



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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

DETERMINING THE PVT PROPERTIES OF A HYDROCARBON RESERVOIR  
FLUID

The present invention relates to determining the PVT properties of a hydrocarbon reservoir fluid, where PVT is an acronym used to refer to pressure, volume and temperature. PVT properties are gas-oil ratio, API gravity, viscosity, saturation pressure, formation volume factor, molecular weight, density and oil compressibility.

In order to measure the PVT properties of a hydrocarbon reservoir fluid, a sample of the reservoir fluid is taken and analysed under reservoir pressure and temperature. A brief description of the way in which a PVT analysis is carried out is given in section 3 of the book Contributions in Petroleum Geology and Engineering, Volume 5, Properties of Oils and Natural Gases, K.S. Pederson et al, 1989. Such an analysis can be very accurate, however it takes a long time to be completed.

It is of great importance to know the PVT properties of the reservoir fluid as soon as possible, preferably directly after a well has been drilled. Because, then there is still a possibility to adjust the design of the production and surface equipment to take into account the actual PVT properties.

Applicant has found that there are empirical relations between the PVT properties and the pressure gradient ( $dp/dz$ ) in the reservoir, wherein  $p$  is the fluid pressure in the reservoir and  $z$  the true vertical depth. Because the pressure gradient can be determined directly after completing drilling, the PVT properties can be obtained as early as possible.

5 Thereto the method of determining at least one of the  
in situ PVT properties of a hydrocarbon reservoir fluid  
that is present in a hydrocarbon-bearing formation layer  
traversed by a borehole according to the present  
invention comprises the steps of:

a) calculating along the hydrocarbon-bearing formation  
layer the pressure gradient; and

b) determining the in situ PVT property from the  
pressure gradient using an empirical relation that had  
10 been obtained by fitting a curve through previously  
obtained data points comprising the measured PVT property  
as a function of the pressure gradient.

15 The method will now be described by way of example in  
more detail with reference to the accompanying drawings,  
wherein

20 Figure 1 shows the gas-oil ratio in standard cubic  
feet per standard barrel on the y-axis as a function of  
the pressure gradient in psi per foot (at in situ  
pressure and temperature) on the x-axis;

Figure 2 shows the API gravity in °API on the y-axis  
as a function of the pressure gradient in psi per foot  
(at in situ pressure and temperature) on the x-axis;

25 Figure 3 shows the viscosity in centipoise (at in  
situ pressure and temperature) on the y-axis as a  
function of the pressure gradient in psi per foot (at in  
situ pressure and temperature) on the x-axis;

30 Figure 4 shows the saturation pressure in psi  
absolute on the y-axis as a function of the pressure  
gradient psi per foot (at in situ pressure and  
temperature) on the x-axis;

Figure 5 shows the formation volume factor, oil on  
the y-axis as a function of the pressure gradient in psi  
per foot (at in situ pressure and temperature) on the  
x-axis; and

Figure 6 shows the molecular weight on the y-axis as a function of the pressure gradient psi per foot (at in situ pressure and temperature) on the x-axis.

With reference to the Figures, we will now discuss  
5 the method of determining at least one of the in situ  
PVT properties according to the present invention in  
reverse order, wherein we start with discussing how the  
empirical relation is obtained.

10 The curves shown in Figures 1-6 show the empirical  
relation, line i1, that fits the data points i2, i3 and  
i4, where i is the number of the Figure (i=1-6) obtained  
from samples taken from reservoirs in the same geological  
area. For the sake of clarity not all data points have  
been referred to by a reference numeral.

15 A data point was obtained as follows. At first a well  
was drilled to the formation layer containing a  
hydrocarbon reservoir fluid. Then a tool was lowered to  
the first of a set of locations in that formation layer  
by means of for example a wireline. The tool comprises a  
20 central conduit having an inlet and being provided with a  
pressure sensor, and a fluid receptacle having an inlet  
opening into the central conduit. At the location an  
exclusive fluid communication was made between the  
formation and the inlet of the central conduit by  
extending into the formation a probe having an outlet  
25 that is in direct fluid communication with the inlet of  
the central conduit. Then formation fluid was allowed to  
enter into the fluid receptacle and the pressure build-up  
was measured. The required fluid pressure is the pressure  
30 at the end of the pressure build-up for that location.

Then the tool was moved to the next location where  
the pressure-build up was again measured to obtain the  
fluid pressure for that location, and so on until all the  
fluid pressures at all locations had been determined.

35 With this the pressure gradient was determined.

Then a sample of the hydrocarbon reservoir fluid was taken, and the PVT properties of the sample were measured in a laboratory under reservoir conditions. And the measurements gave a data point in Figures 1-6.

To get all data points these data were collected and analysed for more wells in the same geological area.

Then for each PVT property a curve was fitted through the data, and surprisingly, the data could be fitted with a considerable accuracy, with a goodness of fit  $R^2$  of

$$10 \quad \text{greater than } 0.9, \text{ wherein } R^2 = \frac{\left( \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y}) \right)^2}{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2},$$

wherein  $n$  is the number of data points,  $(x_1, \dots, x_n)$  is the set of pressure gradients,  $\bar{x}$  is the mean pressure gradient,  $(y_1, \dots, y_n)$  is the set of measurements of the PVT property and  $\bar{y}$  is the mean PVT property.  $R^2$  is the squared value of the correlation coefficient.

15 The below Table gives the results of the curve fitting.

PVT property	Curve	$R^2$
Gas oil ratio	$(8.6)(dp/dz) - 4.2$	0.98
API gravity	$65 - (117)(dp/dz)$	0.91
Viscosity	$(0.0005) \exp(24dp/dz)$	0.96
Saturation pressure	$(16980) \exp(-3.6dp/dz)$	0.72
Formation volume factor	$(0.10)(dp/dz) - 2.3$	0.97
Molecular weight	$(5.2) \exp(8.9dp/dz)$	0.98

The correlation can as well be obtained for other PVT properties, such as density and oil compressibility.

20 We now discuss how a PVT property of an unknown hydrocarbon reservoir fluid that is present in a hydrocarbon-bearing formation layer traversed by a

borehole is determined in situ. Suitably, the hydrocarbon-bearing formation layer is in the same geological area.

At first a tool is lowered to the first of a set of locations in that formation layer. The tool comprises a central conduit having an inlet and being provided with a pressure sensor, and a fluid receptacle having an inlet opening into the central conduit. At the location an exclusive fluid communication is made between the formation and the inlet of the central conduit by extending into the formation a probe having an outlet that is in direct fluid communication with the inlet of the central conduit. Then formation fluid is allowed to enter into the fluid receptacle and the pressure build-up was measured. The required fluid pressure is the pressure at the end of the pressure build-up for that location.

Then the tool is moved to the next location where the pressure-build up is again measured to obtain the fluid pressure for that location, and so on until all the fluid pressures at all locations have been determined. With this the pressure gradient is calculated.

Then the pressure gradient is used with the empirical relation to get the PVT property that is required.

This shows that with the method according to the present invention a good accuracy can be achieved.

In case the hydrocarbon reservoir fluid is a so-called heavy oil that is relatively viscous, it will be difficult to acquire a representative sample of the reservoir fluid. In order to obtain a representative sample, the step of making an exclusive fluid communication further includes activating a heating device arranged near the probe to heat the formation fluid.

Suitably, the probe is associated with a packer pad in an assembly, and the heating device is placed in the

5 packer pad. Alternatively the heating device is arranged on the tool. The heating device may be a device generating microwaves, light waves or infrared waves. The heating device may also be an electrical heater, a chemical heater or a nuclear heater.

10 So far the present invention has been discussed with reference to an open hole, however, the present invention can as well be applied in a cased hole. In that case, calculating the pressure gradient along the hydrocarbon-bearing formation layer starts with making a plurality of perforation sets through the casing wall into the formation layer. Then the tool is lowered in the cased borehole to the first perforation set. The tool is further provided with an upper and a lower packer  
15 arranged at either side of the inlet of the central conduit, wherein the distance between the upper and the lower packer is larger than the height of a perforation set, and wherein the spacing between adjacent perforation sets is at least equal to the length of the longest packer. The packers are set so that the perforation set is straddled between the packers. Then formation fluid is allowed to enter into the fluid receptacle, the pressure build-up is measured, and the fluid pressure is determined. Then the tool is positioned near the next  
20 perforation set, and the fluid pressure is measured and so on, until the fluid pressures of a predetermined number of locations have been measured. From these fluid pressures and the true vertical depths of the casing sets, the pressure gradient is calculated.  
25

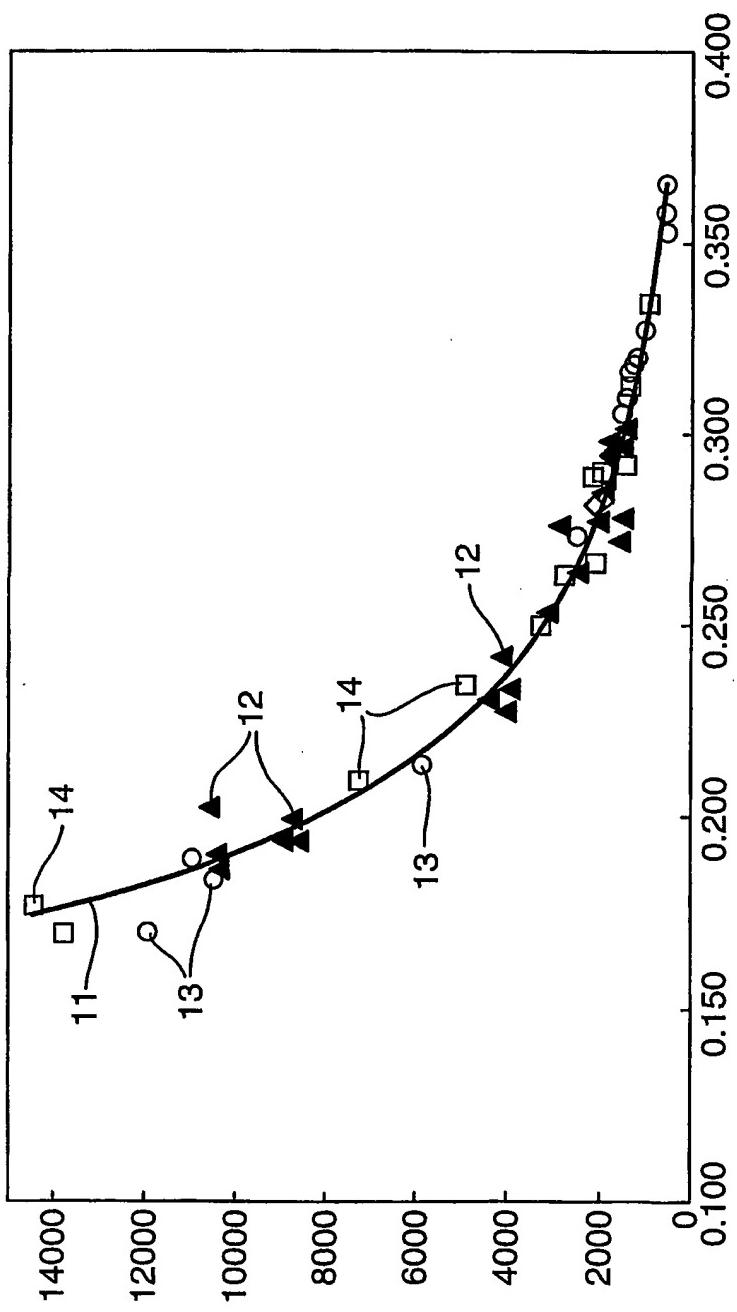
C L A I M S

1. A method of determining at least one of the in situ PVT properties of a hydrocarbon reservoir fluid that is present in a hydrocarbon-bearing formation layer traversed by a borehole, which method comprises the steps of:
  - a) calculating along the hydrocarbon-bearing formation layer the pressure gradient; and
  - b) determining the in situ PVT property from the pressure gradient using an empirical relation that had been obtained by fitting a curve through previously obtained data points comprising the measured PVT property as a function of the pressure gradient.
2. The method according to claim 1, wherein calculating the pressure gradient along the hydrocarbon-bearing formation layer according to step a) comprises the steps of:
  - a1) lowering a tool is to the first of a set of locations in that formation layer, which tool comprises a central conduit having an inlet and being provided with a pressure sensor and a fluid receptacle having an inlet opening into the central conduit;
  - a2) making an exclusive fluid communication between the formation and the inlet of the central conduit;
  - a3) allowing formation fluid to enter into the fluid receptacle and measuring the pressure build-up until no change in measured pressure is observed to obtain the fluid pressure;
  - a4) moving the tool to the next location, and measuring the fluid pressure for that location, and so on until all the fluid pressures at all locations have been measured; and

- a5) calculating the pressure gradient.
3. The method according to claim 2, wherein making an exclusive fluid communication between the formation and the inlet of the central conduit comprises extending into the formation a probe having an outlet that is in direct fluid communication with the inlet of the central conduit of the tool.
- 5
4. The method according to claim 3, wherein making an exclusive fluid communication further includes activating a heating device arranged near the probe to heat the formation fluid.
- 10
5. The method according to claim 2, wherein the borehole is cased and wherein the step of calculating the pressure gradient along the hydrocarbon-bearing formation layer according to step a) comprises the steps of:
- 15
- a1) making a plurality of perforation sets through the casing wall into the formation layer;
- a2) lowering the tool into the cased borehole to the first perforation set, which tool is further provided with an upper and a lower packer arranged at either side of the inlet of the central conduit, wherein the distance between the upper and the lower packer is larger than the height of a perforation set, and wherein the spacing between adjacent perforation sets is at least equal to the length of the longest packer;
- 20
- a3) setting the packers so that the perforation set is straddled between the packers, allowing formation fluid to enter into the fluid receptacle, measuring the pressure build-up, and determining the fluid pressure;
- 25
- a4) positioning the tool near the next perforation set, and repeating step a3) until the fluid pressures of a predetermined number of locations have been measured; and
- 30
- a5) calculating the pressure gradient.

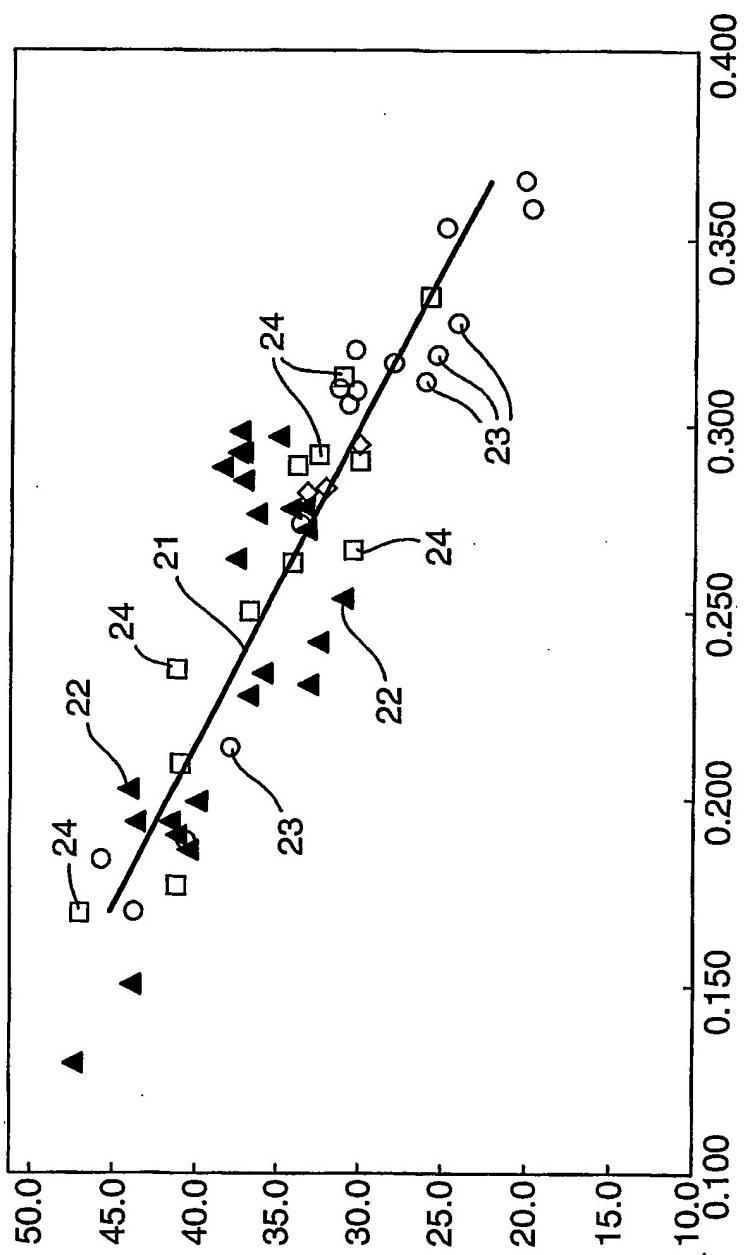
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Fig. 1.



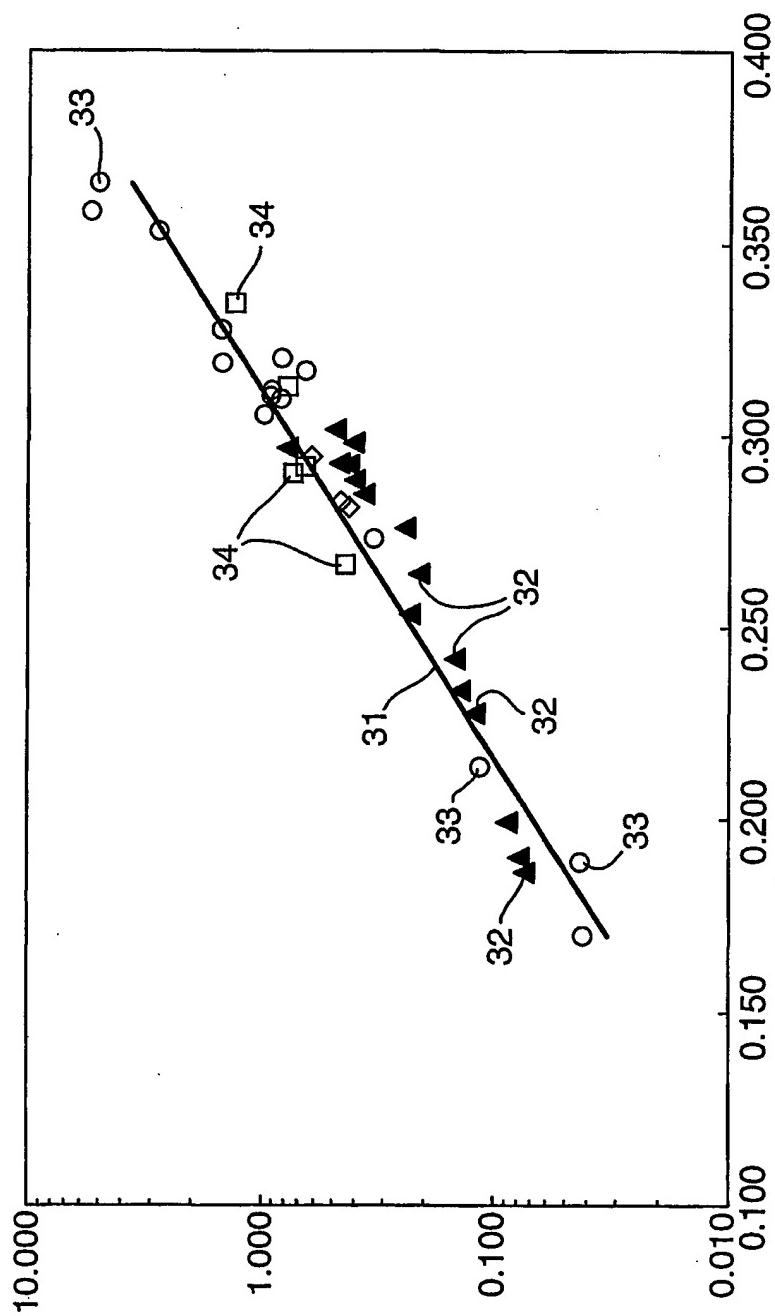
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Fig.2.



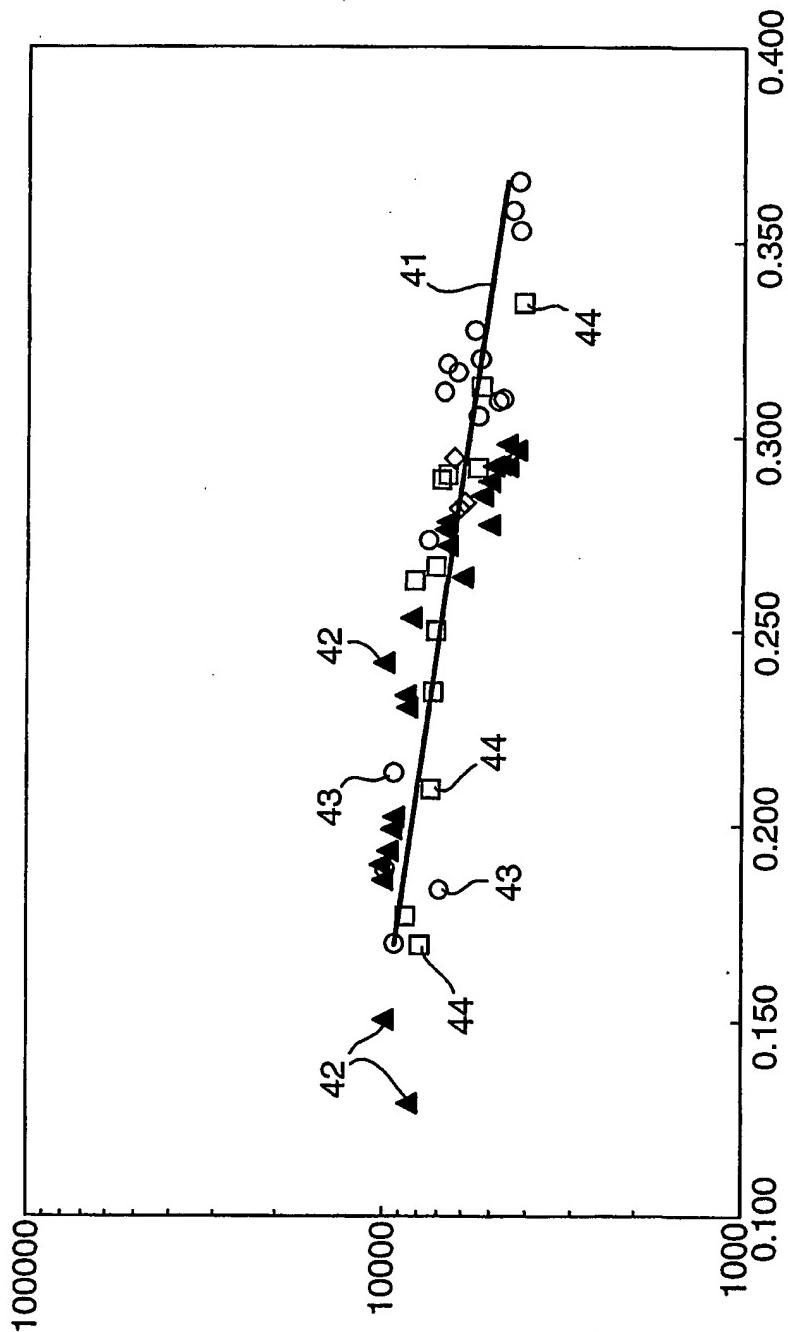
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Fig. 3.



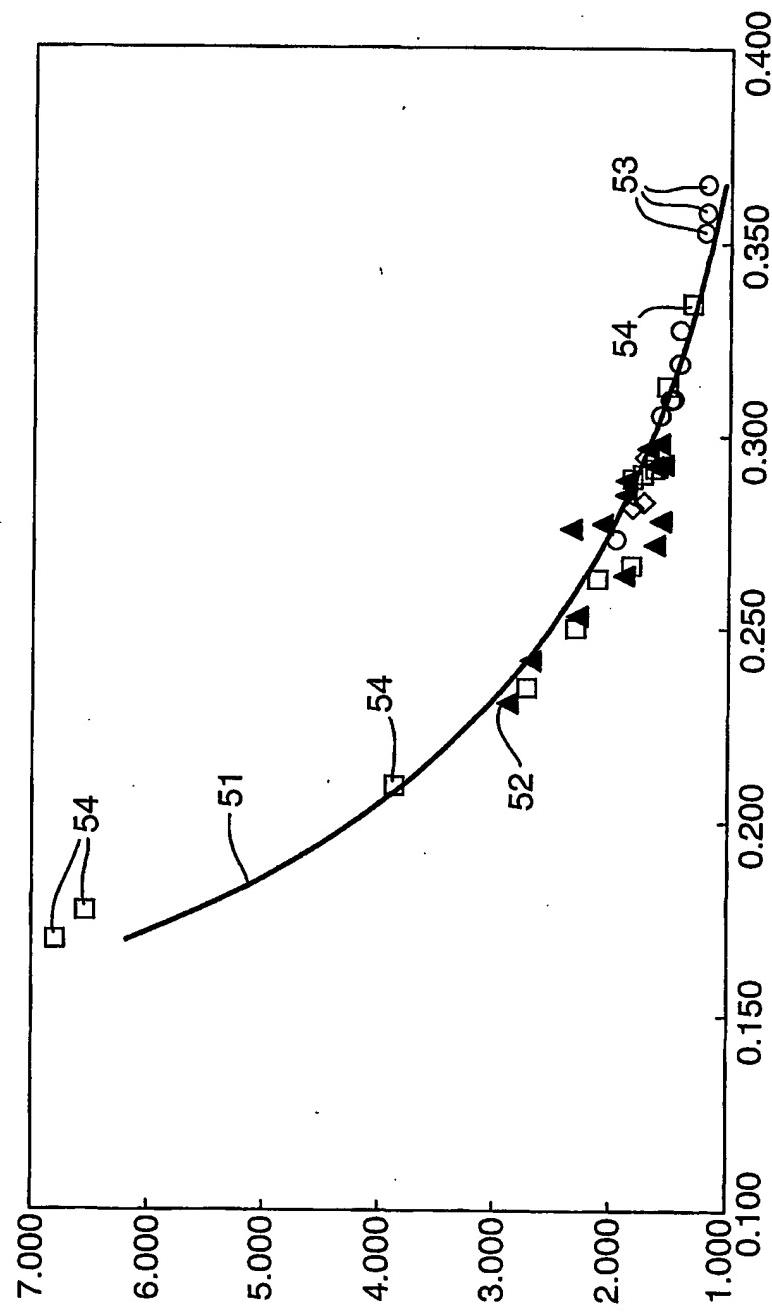
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Fig.4.



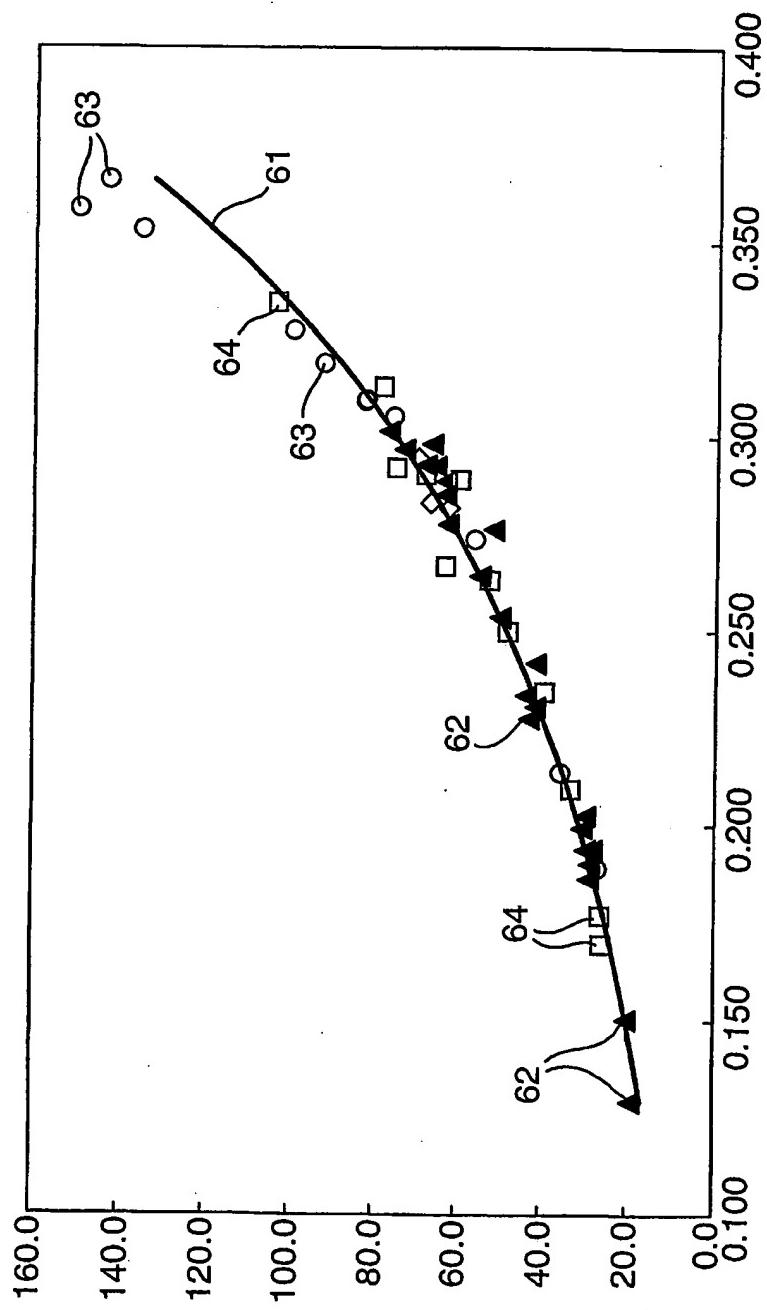
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Fig. 5.



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Fig.6.



## INTERNATIONAL SEARCH REPORT

Int'l Application No  
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A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 E21B49/08

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

TULSA, EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RIDHA B.C. GHARBI ET AL: "Neural Network Model for Estimating the PVT Properties of Middle East Crude Oils" SPE RESERVOIR EVAL. & ENG. (SPE PAPER # 56850), vol. 2, no. 3, June 1999 (1999-06), pages 255-265, XP002169671 the whole document ---	1
A	N. VAROTYSIS: "A Non-Iterative Method for the Prediction of the PVT Behavior of Reservoir Fluids" SPE # 56745, 3 October 1999 (1999-10-03), pages 1-9, XP002169672 the whole document ---	1
	-/-	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

## \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
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Date of the actual completion of the International search

7 March 2002

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## Name and mailing address of the ISA

European Patent Office, P.B. 5018 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel: (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3018

## Authorized officer

Schouten, A

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International Application No.

PCT/EP 02/00517

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 778 154 A (BONE RUSSELL L ET AL) 7 July 1998 (1998-07-07) claim 1 -----	1

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

I	Application No
PCT/EP 02/00517	

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5778154	A 07-07-1998	NONE	